Published in final edited form as:

J Comput Assist Tomogr. 2011 ; 35(2): 212–216. doi:10.1097/RCT.0b013e3182032537.

Feasibility of Simultaneous CT Colonography and Fully-Automated Bone Mineral Densitometry in a Single Examination

Ronald M. Summers, MD, PhD¹, Nicolai Baecher, MD¹, Jianhua Yao, PhD¹, Jiamin Liu, PhD¹, Perry J. Pickhardt, MD², J. Richard Choi, ScD, MD³, and Suvimol Hill, MD¹

¹ Imaging Biomarkers and Computer-Aided Diagnosis Laboratory, Radiology and Imaging Sciences Department, National Institutes of Health Clinical Center, Bethesda, MD 20892-1182

² Department of Radiology, University of Wisconsin School of Medicine & Public Health, E3/311 Clinical Science Center, 600 Highland Ave., Madison, WI 53792

³ Walter Reed Army Medical Center, Washington, DC 20307

Abstract

PURPOSE—To show the feasibility of calculating the bone mineral density (BMD) from CT colonography (CTC) scans using fully-automated software.

MATERIALS AND METHODS—Automated BMD measurement software was developed that measures the BMD of the first and second lumbar vertebrae on a CT scan and averages the two values to provide a per patient BMD estimate. The software was validated in a reference population of 17 consecutive women who underwent QCT and in a population of 475 women from a consecutive series of asymptomatic patients enrolled in a CTC screening trial conducted at three medical centers.

RESULTS—The average ($\pm$ st. dev) BMD was 133.6 $\pm$ 34.6 mg/cc (95% CI [130.5, 136.7]) (n=475). In women aged 42–60 (n=316) and 61–79 (n=159), the average BMDs were 143.1 $\pm$ 33.5 mg/cc and 114.7 $\pm$ 28.3 mg/cc, respectively (p<0.0001). Fully automated BMD measurements were reproducible for a given patient with 95% limits of agreement of [–9.79, 8.46] mg/cc for the mean difference between paired assessments on supine and prone CTC.

CONCLUSION—Osteoporosis screening can be performed simultaneously with screening for colorectal polyps.

Keywords

radiology; population studies; bone densitometry; bone QCT; osteoporosis

Corresponding Author and Reprint Requests: Ronald M. Summers, M.D., Ph.D., Imaging Biomarkers and Computer-Aided Diagnosis Laboratory, Radiology and Imaging Sciences Department, National Institutes of Health Clinical Center, Bldg. 10, Room 1C368X MSC 1182, BETHESDA MD20892-1182, Phone: (301) 402-5486, FAX: (301) 451-5721, rms@nih.gov, Web: <http://www.cc.nih.gov/drd/summers.html>.

Presented in part at the 2009 ASBMR and RSNA Annual Meetings.

Potential financial interests

Author Summers has pending and/or awarded patents for the subject matter described in the manuscript and receives royalty income for a patent license from iCAD. He is a Johnson & Johnson stockholder. His lab is supported in part by a Cooperative Research and Development Agreement with iCAD. Viatronix supplied the V3D Colon software to NIH free of charge. Author Pickhardt is on the medical advisory boards of Viatronix, Inc. and Medicsight, Inc., a consultant to Philips and co-founder of VirtuoCTC. Author Choi is on the medical advisory boards of Viatronix, Inc and QI and has received research support from E-Z-EM. All other authors have no conflicts of interest.

Osteoporosis and colorectal cancer have notable similarities. Both are underdiagnosed in the general population and both strike a similar spectrum of patients. The risk for either disease increases for patients over 50 years of age and for those who lead a sedentary lifestyle [1–5]. Both diseases are highly treatable if detected early. Colorectal cancer can be prevented if colonic polyps are found and removed. Similarly, future fracture occurrence and further loss of bone strength can be mitigated if osteopenia or osteoporosis is detected early and corrected.

Both osteoporosis and colorectal polyps are affected by calcium and vitamin D intake. Chronically low levels of calcium intake are associated with the development of osteoporosis, particularly in women [1]. Evidence from several large studies indicates that higher long-term calcium and vitamin D intake leads to a modest reduction in colonic adenoma incidence and prevalence [6–8]. There is some evidence that the preventative effect is more pronounced for histologically advanced polyps [9].

Both osteoporosis and colorectal polyps and cancers can be detected by CT via CT bone densitometry (QCT or quantitative CT) and CT colonography (CTC), respectively [10–12]. However, at this time these two CT tests are not typically done simultaneously. Given the similar profile of patients at risk, the ability to screen for both diseases with one CT scan to limit radiation dose and expense would be attractive.

The purpose of this study was to show the feasibility of calculating the bone mineral density (BMD) from CTC scans using fully-automated software.

MATERIALS AND METHODS

Patient Population

The patients were a subset of those enrolled in a previously published CTC clinical trial [13]. The original patient population was 1253 consecutive asymptomatic adults with ages ranging from 40 to 79 years of age who met various inclusion and exclusion criteria for CTC. 1233 of these patients completed same-day optical colonoscopy and abdominal CT scans. An additional 47 patients were excluded due to incomplete restoration or location of their CT images. From the resulting 1186 patients, 486 were women, and of these women, 11 were excluded due to failure of the automatic spinal segmentation leaving 475 women, ranging from 42 to 79 years of age. The main reasons for the failure of automated spine segmentation were 1) spinal metallic fixation devices; and 2) patients in decubitus position or not a normal position and the spine is not in the center of the image. We focused on women because they would be expected to have a wider range of bone mineral densities than men and because we had access to a sufficient number of dedicated QCT scans on women for the calibration component of the study. Our institution's Office of Human Subjects Research declared this research exempt from IRB review.

CT colonography

Following a cathartic bowel preparation and administration of oral barium sulfate and sodium diatrizoate for fecal and fluid tagging, the patients underwent CT colonography. A rectal tube was placed and the colon insufflated with room air using patient-controlled manual insufflation.

CT Scanning Parameters

Each patient had a supine and a prone abdominal CT scan taken during a single breath hold using a 4-channel or 8-channel CT scanner (General Electric LightSpeed or LightSpeed Ultra; GE Healthcare Technologies, Waukesha, WI). Intravenous contrast was not used. The

parameters for the scans were 1.25- to 2.5-mm section collimation, 15 mm/s table speed, 1-mm reconstruction interval, 100 mAs, and 120 kVp. The purpose of the supine and prone scanning was to enable detection of polyps in portions of the colon that are collapsed or fluid-filled on one of the two scans but not the other [14].

Automatic ROI placement

Using a research computer program, the spinal column was automatically identified and segmented in three dimensions from the CT images (Figure 1) [15]. The program locates the spinal canal first as a relevant anatomical landmark and starting point, then identifies each of the vertebral bodies. Vertebral level is identified and labeled by the computer via the relative location of the ribs. The lowest rib is used to identify T12, and the remaining vertebrae are automatically segmented by detection of the intervertebral disc and labeled accordingly.

After the 3D segmentation was complete, the software automatically placed 3D regions-of-interest (ROI) encompassing the entire L1 and L2 vertebral bodies (Figure 1). Then, the cortex of each vertebral body was excluded using an adaptive morphological erosion so that the final ROI included only trabecular bone. For each ROI at L1 and L2, the mean of the CT attenuation values within was output to a file. The mean CT attenuation values for L1 and L2 were then averaged. We made measurements at the L1 and L2 levels only, which have been shown to be appropriate levels for assessment of BMD [16].

BMD Estimation

Standard QCT scans contain an external reference phantom placed underneath the patient during the CT scan. The phantom contains multiple tubes of known mineral concentrations of K_2HPO_4 ; this allows for the construction of a calibration curve for estimating the mineral density in the trabecular space of the vertebrae. However, when conducting a retrospective bone density analysis on scans without a reference phantom obtained primarily for CTC, it is necessary to use a different method for estimating BMD.

The method we used was to create a calibration curve from the phantoms in dedicated QCT scans. The curve maps CT attenuation in HU to bone mineral density in mg/cc. We then used this calibration curve to convert the mean trabecular bone CT attenuation on the CTC scans to give a BMD estimation.

The calibration curve was calculated from 18 dedicated QCT patient scans from our radiology database (18 women aged 46–68 years, mean 54 years). The use of the data for these subjects was approved by our IRB and informed consent was waived. The women were a consecutive series having reported BMD < 200 mg/cc; one subject who was scanned using a nonstandard technique was excluded leaving 17 subjects. QCT was done on General Electric Lightspeed CT scanners using 2.5 mm collimation, 2.5 – 3.75 mm reconstruction interval, 120 kVp, 100–200 mA, 1.7 sec exposure time. An external reference phantom was scanned with each patient (Mindways, Austin, TX).

Because the reconstruction interval was thicker on these images, the automated spine partitioning could not be done, so we manually specified the slice numbers for the L1 and L2 vertebral bodies; however, the ROI placement was still automated. As was done for the CTC scans, the cortex of L1 and L2 was excluded and the mean CT attenuation values were averaged. Next, we manually measured the mean CT values of the phantoms for all the subjects. The CT values of the phantoms were adjusted for water content using a correction factor supplied by the manufacturer (Mindways). Then, a linear regression curve was calculated based on the CT values of the phantoms and the known equivalent BMD of the phantoms. This curve maps CT attenuation in HU to bone mineral density in mg/cc. We then used this calibration curve to convert the mean trabecular bone CT attenuation on the QCT

patients and CTC patients to give a BMD estimation. For comparison with the automated measurements, BMD estimates of the QCT scans calculated prospectively by a radiologist using clinical analysis software (using QCT Pro software, versions 3.2 , 4 or 4.1) were obtained.

Quality and consistency check using the supine and prone BMD estimates

Because the analysis was performed by automated software, we evaluated the reproducibility and precision of the measurements by comparing the BMD for the supine and prone CTC scans of each patient. The rationale for this check was that the BMD estimates measured on the supine and prone CTC scans of each patient should be identical within clinically acceptable bounds. We computed the differences in the BMD estimates from the supine and prone scans.

Classification of Osteopenia and Osteoporosis

For DXA, T-scores can be used to classify patients as having osteopenia (between -1 and -2.5) or osteoporosis (-2.5 or lower) according to WHO osteoporosis criteria [17]. T-score criteria for making these diagnoses on QCT have not been established although the use of BMD scores has been advocated (osteopenia, 80–120 mg/cc; osteoporosis, <80 mg/cc corresponding to a T-score of approximately -3) [18,19]. We classified the patients as having osteopenia or osteoporosis according to these ranges of BMD scores.

Statistical Analyses

Linear regression and Bland-Altman analysis were performed to compare BMD measurements made on the QCT scans using the automated software and those made using the standard clinical software [20]. The BMD calculated from the supine CTC scans were used for these analyses. A Bland-Altman analysis of the differences between the supine and prone BMD measurements was performed.

RESULTS

The calibration equation computed from the phantoms in the 17 QCT scans that converted CT attenuation (HU) to bone mineral density (mg/cc) was $BMD = 0.7574 * [CT \text{ attenuation}] + 0.5302$. For the 17 calibration patients, the correlation (r^2) between the automated method and the radiologist's read was 0.98 ($p < 0.0001$). The Bland-Altman 95% limits of agreement comparing the BMD estimates from the automated method and the radiologist's read were [-15.0, 8.8] mg/cc. On the basis of BMD criteria, all seven osteoporotic patients were correctly classified.

A Bland-Altman plot of the comparison of the supine and prone BMD estimates is shown in Figure 2. BMD measurements were available for both the supine and prone CTC scans for 470 patients (the BMD could not be computed for 5 prone CTC scans). There were 27 outliers. In 13 patients, the software misidentified the vertebral level on either or both scans leading to measurement at discordant levels. In two patients, the vertebral levels were identified correctly but there was a lumbar scoliosis and the software had difficulty locating the trabecular bone. In three patients, beam hardening artifact from contrast agent within bowel lowered the measured bone mineral density on the supine scan but not the prone scan. This occurred because the dependent location of the oral contrast on the supine scan was at the same anteroposterior position as the spine but on the prone scan the oral contrast shifted away from the spine due to gravity. In six patients, there was inaccurate segmentation of the trabecular bone. In one patient, degenerative disk disease led to incorrect location of the intervertebral disk. In one patient there was excessive image noise. In one patient, the cause was unknown.

The average ($\pm$ st. dev) BMD was 133.6 ± 34.6 mg/cc (95% CI [130.5, 136.7]) ($n=475$). In women aged 42–60 ($n=316$), the average BMD was 143.1 ± 33.5 mg/cc and in women aged 61–79 ($n=159$) it was 114.7 ± 28.3 mg/cc ($p < 0.0001$). On the basis of BMD criteria, 160 (33.7%) women were classified as osteopenic and 17 (3.6%) as osteoporotic. Example CT images are shown in Figure 3.

DISCUSSION

In this paper, we showed that quantitative CT for bone densitometry can be performed simultaneously with CT colonography for polyp detection. We used a bone densitometric method that did not rely upon an external phantom and calibrated the method using 17 QCT scans. We calculated the bone mineral density for a consecutive series of 475 women who underwent CT colonography. Very few of the women were osteoporotic by QCT criteria. The data comparing the BMD's measured on the supine and prone CTC scans indicated that the measurements were highly reproducible.

The bone mineral densities we found were comparable to those reported for Greek women [21] and higher than those reported for a group of older women [22]. The rates of osteopenia and osteoporosis were lower than those reported by the National Osteoporosis Foundation and more recently from investigation of NHANES data for women aged 50 and older [23–26]. It may be that women in this cohort were more physically active than the general patient population or were being treated for osteoporosis.

A number of investigators have performed quantitative CT without an external reference phantom. Such methods have used internal references (muscle and fat) instead of a phantom and have been found to be highly reproducible and precise and to compare favorably with traditional QCT [27,28]. However, in initial experiments we conducted (data not shown), we found the measurement of muscle and fat as internal references for automated BMD analysis to be less reproducible than the method presented here. It was often difficult to accurately assess both fat and muscle on both the supine and prone scans, particularly in patients with little fat or muscle on the CT slice-of-interest.

Techniques for automated analysis of QCT of the lumbar spine had been previously presented. Mastmeyer et al. presented a hierarchical 3-D spine segmentation method [29]. Their system showed low intra- and inter-operator precision errors and bias for assessment of bone mineral density using existing clinical patient data sets. However, their system could not label the vertebrae automatically.

The WHO criteria for osteopenia and osteoporosis were developed for DXA scanning and are not directly transferrable to QCT [10]. Because QCT measurements are made of the trabecular bone and exclude the cortex, BMD measured at QCT is typically lower than that measured at DXA. The BMD's we found (≥ 70 mg/cc) therefore span a range from normal to osteoporotic. The lower bound is at or near the threshold for initiating treatment and is associated with increased fracture risk.

Automated assessment of bone mineral density at CT colonography could be incorporated into standard CTC interpretation software or applied retrospectively to existing CT scan data to aid investigation and diagnosis. Automated methods of colonic polyp detection at CTC have already been developed [30–32]. It may be possible using these CT scans to conduct finite element analyses to predict future fractures [33].

Given recent renewed concerns about medical sources of radiation exposure, a combined low-dose CT colonography and bone densitometry study may be attractive to clinicians and to the public [34]. CT colonography is a potentially low dose examination, with effective

doses under 6 millisievert achievable in some studies [35,36]. The combination of CTC and bone densitometry in a single examination may both save dose and be more economical compared to CTC plus a separate DXA.

This study has several limitations. We only studied women. We did not include a correction for variation in height of the CT scanner table, although a phantom experiment we performed indicated that such variability was small (data not presented). The BMD we calculated for an individual patient may not be sufficiently accurate for clinical management but may nevertheless be useful for population studies such as this one, or to refer an individual patient for more definitive tests such as QCT or DXA. No intra-patient reference standard was available for the CTC patients (e.g., DXA or QCT with a phantom).

In summary, we found that screening for low BMD can be performed simultaneously with screening for colorectal polyps using CT colonography.

Acknowledgments

We thank Andrew Dwyer, MD, for critical review of the manuscript. We thank Dr. William Schindler for supplying CT colonography data. This work was supported in part by the Intramural Research Program of the National Institutes of Health Clinical Center.

Funding: This work was supported in part by the Intramural Research Program of the National Institutes of Health Clinical Center.

References

1. Cummings SR, Kelsey JL, Nevitt MC, Odowd KJ. Epidemiology of Osteoporosis and Osteoporotic Fractures. *Epidemiol Rev.* 1985; 7:178–208. [PubMed: 3902494]
2. Aloia JF, Cohn SH, Ostuni JA, Cane R, Ellis K. Prevention of Involutional Bone Loss by Exercise. *Ann Intern Med.* 1978; 89:356–358. [PubMed: 686549]
3. Hsing AW, McLaughlin JK, Chow WH, et al. Risk factors for colorectal cancer in a prospective study among US white men. *Int J Cancer.* 1998; 77:549–553. [PubMed: 9679757]
4. Giovannucci E, Ascherio A, Rimm EB, Colditz GA, Stampfer MJ, Willett WC. Physical-Activity, Obesity, and Risk for Colon-Cancer and Adenoma in Men. *Ann Intern Med.* 1995; 122:327–334. [PubMed: 7847643]
5. O'Brien MJ, Winawer SJ, Zauber AG, et al. The National Polyp Study. Patient and polyp characteristics associated with high-grade dysplasia in colorectal adenomas. *Gastroenterology.* 1990; 98:371–379. [PubMed: 2403953]
6. Baron JA, Beach M, Mandel JS, et al. Calcium supplements for the prevention of colorectal adenomas. Calcium Polyp Prevention Study Group. *N Engl J Med.* 1999; 340:101–107. [PubMed: 9887161]
7. Cho E, Smith-Warner SA, Spiegelman D, et al. Dairy foods, calcium, and colorectal cancer: a pooled analysis of 10 cohort studies. *J Natl Cancer Inst.* 2004; 96:1015–1022. [PubMed: 15240785]
8. Grau MV, Baron JA, Sandler RS, et al. Vitamin D, calcium supplementation, and colorectal adenomas: results of a randomized trial. *J Natl Cancer Inst.* 2003; 95:1765–1771. [PubMed: 14652238]
9. Wallace K, Baron JA, Cole BF, et al. Effect of calcium supplementation on the risk of large bowel polyps. *J Natl Cancer Inst.* 2004; 96:921–925. [PubMed: 15199111]
10. Engelke K, Adams JE, Armbrrecht G, et al. Clinical use of quantitative computed tomography and peripheral quantitative computed tomography in the management of osteoporosis in adults: the 2007 ISCD Official Positions. *J Clin Densitom.* 2008; 11:123–162. [PubMed: 18442757]
11. Johnson CD, Chen MH, Toledano AY, et al. Accuracy of CT colonography for detection of large adenomas and cancers. *N Engl J Med.* 2008; 359:1207–1217. [PubMed: 18799557]
12. Frentz SM, Summers RM. Current Status of CT Colonography. *Acad Radiol.* 2006; 13:1517–1531. [PubMed: 17138120]

13. Pickhardt PJ, Choi JR, Hwang I, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. *N Engl J Med*. 2003; 349:2191–2200. [PubMed: 14657426]
14. Yee J, Kumar NN, Hung RK, Akerkar GA, Kumar PR, Wall SD. Comparison of supine and prone scanning separately and in combination at CT colonography. *Radiology*. 2003; 226:653–661. [PubMed: 12601201]
15. Yao, J.; O'Connor, SD.; Summers, RM. Automated spinal column extraction and partitioning. 2006 3rd IEEE International Symposium on Biomedical Imaging: From Nano to Macro - Proceedings; 2006. p. 390-393.
16. Steiger P, Block JE, Steiger S, et al. Spinal bone mineral density measured with quantitative CT: effect of region of interest, vertebral level, and technique. *Radiology*. 1990; 175:537–543. [PubMed: 2326479]
17. Alexeeva, L.; Burkhardt, P.; Christiansen, C., et al. Assessment of Fracture Risk and Its Application to Screening for Postmenopausal Osteoporosis. Geneva: World Health Organization; 1994. Assessment of Fracture Risk and Its Application to Screening for Postmenopausal Osteoporosis; p. 1-129.
18. Link TM, Majumdar S. Osteoporosis imaging. *Radiol Clin North Am*. 2003; 41:813–839. [PubMed: 12899494]
19. Felsenberg D, Gowin W. Bone densitometry by dual energy methods. *Radiologe*. 1999; 39:186–193. [PubMed: 10218211]
20. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986; 327(8476):307–310. [PubMed: 2868172]
21. Karantanas AH, Kalef-Ezra JA, Glaros DC. Quantitative computed tomography for bone mineral measurement: technical aspects, dosimetry, normal data and clinical applications. *Br J Radiol*. 1991; 64:298–304. [PubMed: 2025767]
22. Bauer JS, Henning TD, Mueller D, Lu Y, Majumdar S, Link TM. Volumetric quantitative CT of the spine and hip derived from contrast-enhanced MDCT: conversion factors. *AJR Am J Roentgenol*. 2007; 188:1294–1301. [PubMed: 17449773]
23. Fast Facts on Osteoporosis. [Date Accessed: August 5]. <http://www.nof.org/osteoporosis/diseasefacts.htm>
24. Looker AC, Melton LJ 3rd, Harris TB, Borrud LG, Shepherd JA. Prevalence and trends in low femur bone density among older US adults: NHANES 2005–2006 compared with NHANES III. *J Bone Miner Res*. 2010; 25:64–71. [PubMed: 19580459]
25. Looker AC, Orwoll ES, Johnston CC Jr, et al. Prevalence of low femoral bone density in older U.S. adults from NHANES III. *Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research*. 1997; 12:1761–1768. [PubMed: 9383679]
26. National Osteoporosis Foundation. America's bone health : the state of osteoporosis and low bone mass in our nation. Washington D.C: The Foundation; 2002. p. 55leaves (chiefly tables)
27. Gudmundsdottir H, Jonsdottir B, Kristinsson S, Johannesson A, Goodenough D, Sigurdsson G. Vertebral bone density in Icelandic women using quantitative computed tomography without an external reference phantom. *Osteoporos Int*. 1993; 3:84–89. [PubMed: 8453195]
28. Boden SD, Goodenough DJ, Stockham CD, Jacobs E, Dina T, Allman RM. Precise measurement of vertebral bone density using computed tomography without the use of an external reference phantom. *J Digit Imaging*. 1989; 2:31–38. [PubMed: 2488150]
29. Mastmeyer A, Engelke K, Fuchs C, Kalender WA. A hierarchical 3D segmentation method and the definition of vertebral body coordinate systems for QCT of the lumbar spine. *Med Image Anal*. 2006; 10:560–577. [PubMed: 16828329]
30. Petrick N, Haider M, Summers RM, et al. CT Colonography and Computer-aided Detection as a Second Reader: Observer Performance Study. *Radiology*. 2008; 246:148–156. [PubMed: 18096536]
31. Halligan S, Altman DG, Mallett S, et al. Computed tomographic colonography: assessment of radiologist performance with and without computer-aided detection. *Gastroenterology*. 2006; 131:1690–1699. [PubMed: 17087934]

32. Mang T, Peloschek P, Plank C, et al. Effect of computer-aided detection as a second reader in multidetector-row CT colonography. *Eur Radiol.* 2007; 17:2598–2607. [PubMed: 17351780]
33. Adams JE. Quantitative computed tomography. *Eur J Radiol.* 2009; 71:415–424. [PubMed: 19682815]
34. Goske MJ, Applegate KE, Boylan J, et al. The Image Gently campaign: working together to change practice. *AJR Am J Roentgenol.* 2008; 190:273–274. [PubMed: 18212208]
35. El-Maraghi R, Kielar A. Low-dose computed tomographic colonography versus optical colonoscopy: a critically appraised topic. *Semin Roentgenol.* 2009; 44:191–195. [PubMed: 19480906]
36. Liedenbaum MH, Venema HW, Stoker J. Radiation dose in CT colonography--trends in time and differences between daily practice and screening protocols. *Eur Radiol.* 2008; 18:2222–2230. [PubMed: 18491095]

Figure 1.

Fully-automated CT bone densitometry calculation. Computer software identifies the spine, locates the lowermost (12th) rib and identifies the L1 and L2 vertebral bodies (top images). The software next segments the vertebral body. The segmented vertebra body is then eroded by 5mm to remove the cortical bone and retain the medullary bone (green shaded, lower image of an L2 vertebral body). The mean Hounsfield number within the medullary part of the vertebra bodies of L1 and L2 is used to estimate bone mineral density.

Figure 2.

Bland-Altman plot for the bone mineral densities computed from the supine and prone CT colonography scans ($n = 470$ patients). Bone mineral densities given in mg/cc. The 95% limits of agreement are $[-9.79, 8.46]$ mg/cc.

Figure 3. Example L1 vertebral body transverse CT images showing (A) osteoporosis (54 year old woman) and (B) normal bone mineral density (51 year old woman,). Bone mineral densities for these two patients calculated by automated software (averages of L1 and L2 vertebral bodies) were (A) 59 mg/cc and (B) 207 mg/cc.