Osteoporosis Int (1995) 5:446–449

Osteoporosis International

Original Article

Cortical Thickness Assessed by Peripheral Quantitative Computed Tomography: Accuracy Evaluated on Radius Specimens

O. Louis[1], J. Willnecker[3], S. Soykens[2], P. Van den Winkel[2] and M. Osteaux[1]

[1]Radiology Department and [2]Cyclotron Department, Akademisch Ziekenhuis, Vrije Universiteit Brussel, Brussels, Belgium; [3]Stratec Medizintechnik, Birkenfeld, Germany

Abstract. The purpose of the present study was to evaluate the accuracy of peripheral quantitative computed tomography (pQCT) in measuring the thickness of the radial cortex. Thirty left forearm specimens were scanned on an XCT 960 Stratec pQCT device using a 2.5 mm thick slice at the junction of the middle and the distal third of the radius. Cortical and trabecular areas were assessed using a threshold procedure; cortical thickness was subsequently calculated assuming a circular ring model for the radius. Cortical thickness was also measured on the true shape of bone using an iterative contour detection procedure. Subsequently 2.5 mm thick resin-embedded cylindrical radial specimens, matched with the site of pQCT examination, were obtained and contact radiographs were performed. After tenfold magnification, the cortical and trabecular areas of the specimens were measured using computerized planimetry and cortical thickness was calculated assuming a circular ring model. The cortical thickness could be assessed by pQCT in all cases using the threshold algorithm (mean (SD) 2.51 (0.58) mm) and in 21 cases could be directly measured on the true shape of bone (2.62 (0.32) mm). The cortical thickness of the specimens showed good correlation and high proportionality with that measured using pQCT with either the threshold algorithm (r = 0.941, slope = 0.976) or the iterative contour detection procedure (r = 0.883, slope = 0.987). In conclusion, pQCT is able to assess the thickness of the radial cortex, at the junction of the middle and the distal third, with high accuracy.

Correspondence and offprint requests to: Dr O. Louis, Radiology Department, Akademisch Ziekenhuis, Vrije Universiteit Brussel, Laarbeeklann 101, B-1090, Brussels, Belgium

Keywords: Cortical thickness; Peripheral quantitative computed tomography; Radius

Introduction

In recent years there has been a growing awareness that trabecular osteopenia is not the only risk factor for osteoporotic fracture. More emphasis has been put on cortical bone [1], as it has been shown that small changes in the amount of compact bone make a large difference to bone strength [2,3]. An age-related thinning of the cortical wall has been incriminated as a potential mechanism for osteoporosis [4,5] and previous studies have attempted to assess the size of cortical bone at the level of either the second metacarpal [6], the radius [4,7], the femur [8] or the lumbar vertebrae [9]. Most of these studies were performed using quantitative computed tomography either in vivo [4] or on cadaveric specimens [7,9].

In the present study we studied the thickness of cortical bone at the junction of the middle and the distal third of the radius in 30 forearm specimens, using a Stratec peripheral quantitative computed tomography (pQCT) device. We assessed cortical thickness using two distinct procedures available on the pQCT software (threshold algorithm and iterative contour detection) and compared the values obtained with the thickness measured on resin-embedded specimens, using computerized planimetry on a contact radiograph after photographic magnification. Our objective was to evaluate the accuracy of pQCT in measuring the thickness of the radial cortex.

Materials and Methods

Materials

This study was performed on 30 left forearm speciméns, excised from 30 cadavers obtained from the Anatomy Department of our School of Medicine. All cadavers had been preserved using an injection into the vessels of formalin solution. All were women (mean age 72 years, range 61–85). The cause of death was cerebrovascular insult (11 cases), heart failure (10 cases), acute infection (6 cases) and pulmonary embolism (3 cases). Malignancy, chronic infection, diabetes or treatment known to interfere with bone metabolism were not present in any of the cases.

Methods

Peripheral Quantitative Computed Tomography (pQCT). All scans were performed using a newly developed specially built scanner (single energy pQCT: XCT 960, Stratec, Germany) with an X-ray tube (38.5 kV) as the source of radiation (10). Computed tomographic single slice measurements (2.5 mm thick) were made at a site corresponding to one third of the length of the radius from its distal end. After completion of the scanning, a metal pin was screwed into the forearm specimen at the exact site of the scanned slice. Trabecular and cortical density were assessed separately and expressed as milligrams hydroxyapatite of calcium per millilitre.

Assessment of Cortical Thickness from pQCT Images. The cortical bone was separated from the trabecular bone using research software that included two different procedures:

Threshold algorithm. This procedure separates the voxels by a chosen threshold density, all voxels with a lower attenuation coefficient than the threshold setting being eliminated. We decided to fix the threshold at a linear attenuation coefficient of 0.93 cm^{-1} to minimize the partial volume effect. The software measures the cortical area (A_c) and the trabecular area (A_t); the cortical thickness (T_c) is subsequently calculated – assuming a circular ring model for the radius – using the formula:

$$T_c = \sqrt{\frac{(A_c + A_t)}{\pi}} - \sqrt{\frac{A_t}{\pi}}$$

The reproducibility of cortical thickness evaluated from 10 repeated measurements of two forearms is (coefficient of variation) 1.0–1.2%.

Iterative contour detection. With this procedure, the threshold attenuation coefficient is set automatically by the algorithm. The algorithm automatically finds the first voxel of bone edge, then looks at the neighbouring voxels to determine the next bone edge. This process is continued until the algorithm returns to the start point and the inner and outer contours of the cortical shell are defined. The cortical area thus defined is saved and all other voxels are eliminated. This software provides a direct measurement of cortical thickness, based on the true shape of the bone. The coefficient of variation, calculated on 10 measurements of two specimens as with the threshold algorithm procedure, is 1.1–1.4%.

Preparation of the Specimens. The forearms were dissected after pQCT examination in order to obtain radius specimens. Five millimetre thick slices were cut with a diamond circular saw, each slice including in its central part the 2.5 mm thick region studied on pQCT, located using the metal pin. Every effort was made to cut perpendicular to the long axis of the radius. After removal of endosteal trabecular bone by grinding with carborundum paper, the specimens were embedded in a polyester resin. Subsequently the thickness was reduced to 2.5 mm.

Assessment of Cortical Thickness from Contact Radiographs of the Specimens. We performed contact radiographs of the 30 specimens (Fig. 1). We used a dedicated mammography device (CGR, Paris, France) and high-sensitivity films specifically devised for mammography. Radiographs were performed at 22 kV and 20 mAs. One advantage of this method was that it kept the true dimensions of the specimen. Subsequently we performed a tenfold photographic magnification. In each specimen, the cortical area and the trabecular area were measured using computerized planimetry. An adapted version of the table code Applesoft written for an Apple graphic table coupled with an Apple II computer (Computerland, Brussels, Belgium) was used for planimetric analysis. Repetition of the procedure three times showed good reproducibility, the mean (SD) coefficient of variation on three consecutive measurements being 2.0 (1.2)%. Cortical thickness was subsequently calculated – assuming a circular ring model – using the same formula as that used with pQCT image analysis.

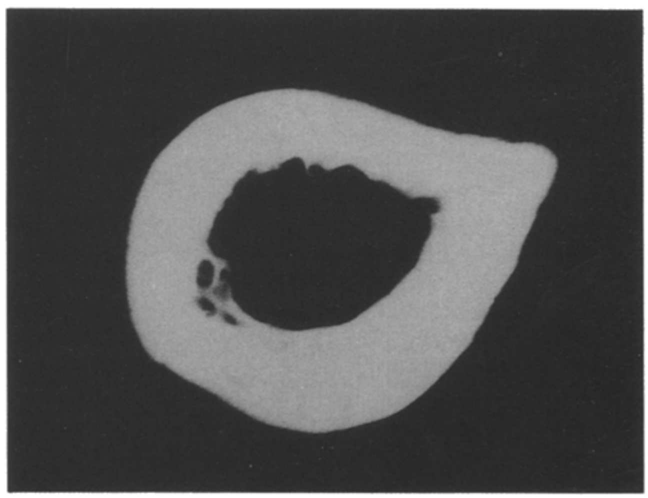

Fig. 1. Contact radiograph of a resin-embedded specimen of radial cortex.

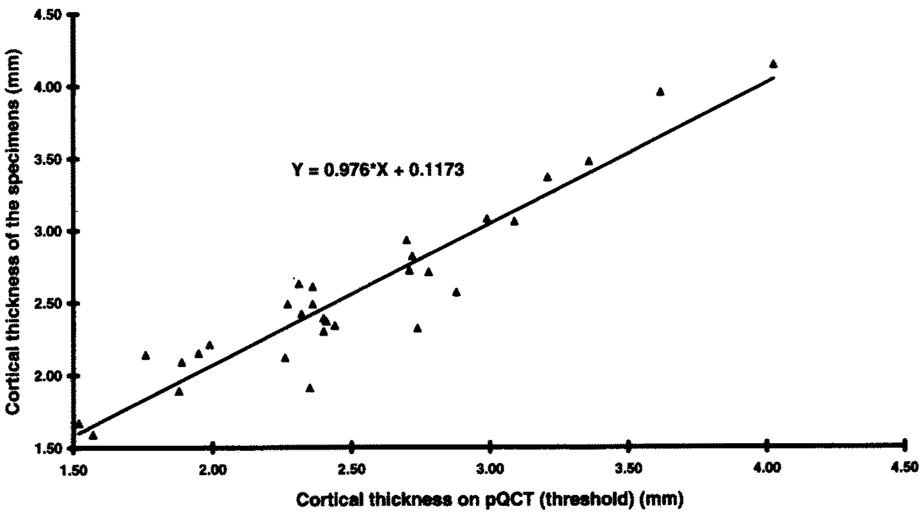

Fig. 2. Linear regression of the cortical thickness calculated by planimetry on the specimens, against the cortical thickness assessed during forearm examination with pQCT, using the algorithm threshold procedure. Both thicknesses are expressed as millimetres.

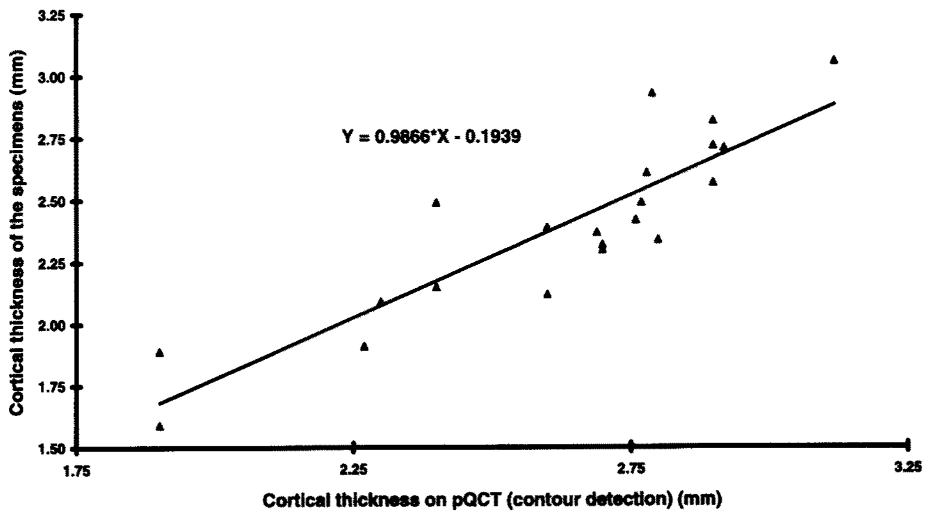

Fig. 3. Linear regression of the cortical thickness calculated by planimetry on the specimens, against the cortical thickness assessed during forearm examination with pQCT, using the iterative contour detection procedure. Both thicknesses are expressed as millimetres.

Results

Mean (SD) cortical thickness assessed on the forearms scanned with the Stratec pQCT device, using the threshold algorithm method, was 2.51 (0.58) mm. Using the iterative contour detection method, cortical thickness could be assessed in 21 cases, while the software failed to provide a measurement in the remaining 9 cases. In this subgroup ($n = 21$) mean (SD) cortical thickness was 2.62 (0.32) mm versus 2.54 (0.50) mm using the threshold algorithm method and a circular ring model assumption. These two measures of cortical thickness showed close correlation ($r = 0.942$).

Mean (SD) cortical density assessed on the forearms was 1259.6 (51.7) mg/ml using the threshold algorithm method and 1277.2 (65.2) mg/ml using the iterative contour detection method. The between-subject coefficient of variation of cortical density was respectively 4.1% and 5.1% with each method.

Mean (SD) cortical thickness assessed on the specimens using planimetric analysis was 2.57 (0.60) mm. The regression lines of the cortical thickness of the specimens (y) versus that measured on the forearms using pQCT (x) are shown in Figs 2 and 3. Equations were $y = 0.976x + 0.12$, $r = 0.941$ (threshold algorithm) and $y = 0.987x - 0.19$, $r = 0.883$ (iterative contour detection). The standard error of the estimate was respectively 0.18 mm (7.2% of the mean) and 0.21 mm (7.6% of the mean).

Discussion

In the present study involving the thickness of cortical bone, we chose the radius as a bone containing a relatively high proportion of compact bone. Indeed in a previous study focused on the cortex of lumbar vertebrae we found that the measured thickness of a thin cortical wall using a segmentation procedure with quantitative computed tomography was heavily influenced by the cut-off chosen for segmentation [9]. We decided to study the radius at the junction between its middle third and its distal third, rather than at the ultradistal site usually assessed for routine mineral density examination [11], because studies based on area moment of inertia have suggested that this junction shows an increased vulnerability to fractures [7]. Furthermore, we focused the study of bone size on cortical wall thickness, rather than on cortical cross-sectional area, since it was recently shown in osteoporotic patients that cortical thickness of the radius is substantially reduced, while cortical area is slightly increased [5].

The mean cortical thickness measured in this study at the junction of the middle third and the distal third of the radius was 2.51 mm, using the threshold algorithm method and a circular ring model assumption. This result compares well with that measured in two previous studies performed with thin slice pQCT. Indeed, Ruegsegger et al. [4], using a Densiscan apparatus, found a mean thickness of 2.35 mm, while Hsu et al. [7], using a Picker International Synerview 1200 SX, showed that the radial cortical thickness is constant around 2.8 mm in the middle third, but decreases towards the proximal and distal ends. Hangartner et al. [12] have emphasized that a constant density of compact bone is necessary for the accurate measurement of cortical thickness. In their experience the between-subject coefficient of variation in cortical density ranges from 2.5% to 4.6%, depending on the bone structure studied [12], while the coefficient of variation in this study varied between 4.1% and 5.1%.

The design of the present study included the cutting of cylindrical radial specimens, centrated on the level examined by pQCT, embedding in a polyester resin, a further reduction to 2.5 mm thick cylindrical specimens, contact radiography and finally computerized planimetry following photographic magnification. This methodology was originally developed in our laboratory on lumbar vertebrae [9,13] and later successfully adapted to radial specimens. This procedure allowed us to evaluate the accuracy of the Stratec pQCT in measuring cortical thickness, taking the thickness calculated from planimetric analysis of the contact radiographs of the specimens as the reference standard. We found that the thickness assessed by pQCT and that measured on the specimens showed a close correlation and a high proportionality. Using the threshold algorithm procedure, pQCT underestimated cortical thickness by 0.12 mm on average, probably because using the 0.93 threshold the calculated outer contour is slightly smaller than the actual one. The iterative contour detection method was able to provide a direct measurement of cortical thickness, based on the true shape of the bone, without making any geometrical assumption, but the procedure failed in a minority of cases. Finally, it should be emphasized that this study involved the junction of the middle and the distal third of the radius and that extrapolation of our results to the ultradistal site usually assessed is currently not legitimate.

Acknowledgements. The authors thank Dr J. P. Clarys for providing the cadaver specimens, Mrs F. Cnapelinckx for secretarial assistance and M. R. Van Den Broeck for drawing the figures.

References

1. Mazess RB. Fracture risk: a role for compact bone. Calcif Tissue Int 1990;47:191–3.
2. Carter DR, Hayes WC. Bone compressive strength: the influence of density and strain rate. Science 1976;194:1174–5.
3. Myers ER, Hecker AT, Rooks DS, Hipp JA, Hayes WC. Geometric variables from DXA of the radius predict forearm load in vitro. Calcif Tissue Int 1993;52:199–204.
4. Ruegsegger P, Durand E, Dambacher MA. Localisation of regional forearm bone loss from high resolution computed tomographic images. Osteoporosis Int 1991;1:76–80.
5. Schneider L, Borner W. Effect of systemic pathologic condition on bone size but not on bone density. Bone Miner 1994;25:39.
6. Derisquebourg T, Dubois P, Devogelaer JP, Meyse E, Duquesnoy B, Nagant de Deuxchaisnes C, et al. Automated computerised radiogrammetry of the second metacarpal and its correlation with absorptiometry of the forearm and spine. Calcif Tissue Int 1994;54:461–5.
7. Hsu E, Patwardhaw AG, Meade KP, Light TR, Martin WR. Cross-sectional geometrical properties and bone mineral contents of the human radius and ulna. J Biomech 1993;26:1307–18.
8. Thompson DD. Age changes in bone mineralisation, cortical thickness, and haversian canal area. Calcif Tissue Int 1980;31:5–11.
9. Louis O, Van den Winkel P, Schoutens A, Osteaux M. Size of cortical bone and relationship to bone mineral density assessed by quantitative computed tomography image segmentation. Invest Radiol 1993;28:802–5.
10. Schneider P, Borner W. Periphere quantitative Computertomographie sur Knochenmineralimessung mit einem neuen speziallen QCT-Scanner. Nuklearmediziner 1988;11:145–52.
11. Butz S, Wuster C, Scheidt-Nave C, Gotz M, Ziegler R. Forearm BMD as measured by peripheral quantitative computed tomography (pQCT) in a German reference population. Osteoporosis Int 1994;4:179–84.
12. Hangartner TN, Gilanz V, State W. Constant cortical density is a requirement for the accurate measurement of cortical thickness by CT. Bone Miner 1994;25:S4.
13. Louis O, Van den Winkel P, Covens P, Schoutens A, Osteaux M. Excision of a trabecular ROI from resin-embedded vertebrae: report on a computer assisted method. Phys Med Biol 1993;38:855–61.

Received for publication 18 November 1994
Accepted in revised form 3 May 1995